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Reliability of Joint Position Sense and Force-Reproduction Measures During Internal and External Rotation of the Shoulder

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Objective: To determine the reliability of 2 common measures of proprioception.

Design and Setting: Joint position sense (JPS) and force reproduction (FR) were measured in the dominant shoulder using internal-rotation (IR) and external-rotation (ER) target angles on 2 consecutive days.

Subjects: Thirty-one healthy subjects (age = 22.0 ± 2.8 years, height = 171.8 ± 9.2 cm, mass = 69.5 ± 15.9 kg) who did not regularly compete in overhand sports volunteered to participate in the study.

Measurements: Error scores were calculated at 2 target angles by averaging the absolute difference of 3 trials of JPS and FR. Reliability was determined by comparing the error scores obtained on 2 consecutive days.

Results: The inclinometer was found to be a reliable instrument as both intertester (.999) and intratester (.999) intraclass correlation coefficients were high. The JPS and FR measurements were also found to be reliable, with intraclass correlation coefficients ranging from .978 to .984. No differences were observed between trials for either measure.

Conclusions: The inclinometer was a reliable instrument and can provide an affordable and accurate measure of range of motion and JPS. Both JPS and FR were also reliable measures of proprioception in the shoulder. Further research is needed to identify the specific mechanism of proprioception during these tasks.

Key Words: proprioception, neuromuscular control, sensorimotor system

The term *proprioception* was first introduced by Sherrington in 1906, who described it as a type of feedback from the limbs to the central nervous system.[1] Since that time, numerous authors have investigated various aspects of proprioception and neuromuscular control, providing us with more information and allowing us to better define proprioception.[2–28] Based on the early descriptions by Sherrington and others, the contemporary terms of joint position sense (JPS), kinesthesia (perception of active and passive motion), and sense of tension or force are considered submodalities of proprioception.[1,29,30]

Proprioceptive information is provided through a variety of receptors in the periphery, including Ruffini receptors, paciniform afferents, and pacinian corpuscles. Paciniform afferents are best activated by compression stimuli.[5] Ruffini receptors and pacinian corpuscles are both classified as dynamic receptors; however, Ruffini receptors have also been described as static receptors based on their low-threshold, slow-adapting characteristics. It has been suggested that these types of receptors are stimulated when a joint is moved near the end range of motion.[5] Two other receptors that play a primary role in proprioception are the muscle spindle and Golgi tendon organ (GTO). The muscle spindle senses changes in muscle length, and the GTO identifies changes in muscle tension. Although the functions of these receptors have been previously established,[31,32] their specific contributions to proprioception are still controversial. The specific mechanism of proprioception with regard to conscious proprioception and motor control is unclear and will be mentioned further in the discussion.

Joint position sense is one of the most commonly used measures of proprioception.[2,6–9,30,33,34] Determining JPS involves measuring the accuracy of joint-angle replication, which can be conducted actively or passively and in an open or closed chain environment.[30] Some of the research involving JPS has included variables such as fatigue, trauma, surgery, and various protocols for rehabilitation or training.[2,10–12] Although the assessment of JPS has become a common measure in research, no one standard method for measuring it has been established. Some have used simple goniometers, and others have used isokinetic dynamometers, electromagnetic tracking devices, or custom-made jigs.[6,11,34,35] Some of the confounding variables in measuring JPS include visual, auditory, and tactile cues from the environment. An inclinometer can provide an affordable and accurate measure of JPS. The small, lightweight inclinometer generates no sound while operating and may provide less tactile feedback than other devices, so it may prove effective in measuring JPS.

The sense of tension or force, commonly assessed using force reproduction (FR), has also been used as a measure of proprioception.[9,14,15–19,29,36,37] Contralateral limb matching has become the preferred method because the numeric observations are power functions of the corresponding stimulus intensities.[20] Assessing FR by limb matching involves the use of a reference force, usually determined as a percentage of a maximal voluntary isometric contraction (MVIC), and attempting to replicate that force. Force matching can occur in the same limb or the contralateral limb. Most authors used one angle to replicate the force produced.[14,15,17,19,20,37] However, muscular tension and the ability to reproduce force might change at various muscle lengths, so measuring FR at different muscle lengths could prove useful.[21] Proprioception can be decreased in those who suffer from shoulder injury.[38] Force reproduction could provide greater afferent information regarding shoulder proprioception; however, research in this area is very limited.

Force reproduction could be of particular interest in the shoulder. Because the glenohumeral joint primarily relies on dynamic restraints to maintain stability, neuromuscular control of the rotator cuff is important to stabilize the glenohumeral joint and prevent injury.[4,39] However, until now, this area of research has been neglected. Previous authors who measured JPS and FR have used a different number of trials, and it is unclear how many should be performed. Two to 6 trials are usually performed and the measurements averaged for the analysis.[2,10] Some of the concerns in performing multiple trials include fatigue and a learning effect. If the data-collection process is long or too strenuous for the subjects, they could fatigue, and the subsequent error scores would be artificially inflated. Previous authors have suggested that fatigue decreases proprioception in the shoulder.[2,10,22] However, repeating unnecessary trials could lead to a learning effect, and results of the subsequent trials could be artificially improved. No investigators to date have measured the difference in trials for JPS or FR testing.

Researchers must establish the reliability of a technique to draw meaningful conclusions from the experiment.[40] Reliability coefficients ranging from .95 to .99 have been reported for JPS,[2,23,35] but authors rarely explain in detail how they obtained the reliability data. At this time, no authors have measured FR in the shoulder, the reliability of FR using a shoulder model, or the reliability of JPS at the shoulder. Thus, our purpose was to assess 2 methods of measuring proprioception by calculating the reliability of the measurement and the device. We proposed no difference between day 1 and day 2 of testing JPS and FR and no difference between angles and trials within the JPS and FR measurements.

METHODS

Subjects

Thirty-one male and female subjects (age = 22.0 ± 2.8 years, height = 171.8 ± 9.2 cm, mass = 69.5 ± 15.9 kg) from the general university population volunteered to participate in the study. Results from a power analysis indicated 30 subjects were sufficient for this study (97%). We excluded any subjects who had previously suffered an injury to the upper extremity that might influence the neuromuscular control characteristics of the shoulder, including previous dislocation, subluxation, or surgery. We also excluded any subjects who had regularly participated in overhand sports or recently exercised their upper body. Before participating, each subject read a description of the study and signed an informed consent form approved by the university institutional review board, which also approved the study.

Figure 1. Inclinometer.

Instrumentation

We used a Kinetic Communicator (Kin Com) 125 AP (Chattanooga Group, Chattanooga, TN) isokinetic dynamometer integrated with a computer and appropriate software to assess FR and inclinometer reliability.

We assessed range of motion (ROM) and JPS using an inclinometer (Figure 1). The inclinometer resembles a flat goniometer with 360 degrees (marked in single-degree increments on the circumference). We determined the angle measured by comparing the location of the arm on the inside of the inclinometer with the degree markings around the circumference. Because the arm can move without restriction, gravity maintains it in the downward position. Thus, during limb movement, the arm remains in the downward position, indicating the change in limb position.

Before the study, we attempted to determine the reliability of this instrument. To accomplish this, we attached the inclinometer to the dynamometer arm of the Kin Com using hook-and-loop straps. One researcher then randomly positioned the dynamometer arm to 10 different angles. At each angle, 2 other researchers (T1 and T2), blinded to the actual position of the dynamometer arm, recorded the angles observed on the inclinometer. The measurement at each angle was repeated 2 more times in random order, for a total of 3 trials at each angle. Intertester reliability was determined by comparing the observed angles recorded by T1 and T2 during the first trial, while intratester reliability was determined by comparing the observed angles recorded by T1 across all 3 trials. In addition, we compared the measurements of the inclinometer and the Kin Com and calculated the validity of the inclinometer to be very high (.999).

PROCEDURES

All testing was completed at the Athletic Training/Sports Medicine Research Laboratory. Upon arrival, each subject's descriptive data and information regarding arm dominance, injury status, and recreational sport activity were recorded. We

Figure 2. Subject position during joint position sense testing.

Figure 3. Subject position during force-reproduction testing.

determined arm dominance as the arm the subject would use to throw a ball. We then assessed each subject for JPS and FR in the dominant limb. Joint position sense was always assessed first; however, the order of the angles tested for both JPS and FR was randomly selected. Each subject returned 24 hours after testing for retesting using the same protocol.

Joint Position Sense Testing

All JPS testing was performed with the subject in the standing position. To begin testing, we securely attached the inclinometer to the subject's wrist using hook-and-loop straps. Range of motion was then assessed for internal rotation (IR) and external rotation (ER) while the shoulder and elbow were maintained in 90° of abduction and flexion, respectively (Figure 2). The subject was instructed to actively rotate the arm to the endpoint of the range in both the IR and ER directions. He or she was further instructed to hold the end position while T1 observed and recorded the angle. We then calculated the repositioning or target angles according to the maximum angle each subject achieved. For the purpose of this study, the 2 target angles were equivalent to 90% of IR and 90% of ER ROM.

To assess JPS, we actively assisted the subject's arm to the target angle with instructions to hold it there for 3 seconds before returning the arm to the starting position. We had used 3 seconds in a previous study.[41] Three seconds is long enough for the subject to identify the position but not long enough to become fatigued during the trial and the JPS testing session. The subject was blindfolded to eliminate any visual cues and, while at the target angle, was told to concentrate on the position of the arm ''in space.'' After returning to the starting point, the subject was instructed to immediately reposition the arm back to the target angle and inform T1 when he or she felt the position had been achieved. At this time, T1 recorded the angle observed on the inclinometer. The measurement was repeated 2 more times for a total of 3 trials, with a 30-second rest period separating trials. We measured the absolute difference between the target angle and the observed angle and calculated the error score by averaging the 3 trials. The individual trials and the error scores were used in the analysis.

Force-Reproduction Testing

Force-reproduction testing was performed with the subject standing and the limb in the same position as for JPS testing. The dynamometer's axis of rotation was aligned with the shoulder's frontal axis of rotation, as the extremity was placed in a position of 90° of shoulder abduction and 90° of elbow flexion. We strapped the subject's wrist to the force transducer on the dynamometer arm using the wrist attachment (Figure 3). All testing was performed with the dynamometer set to gather data in the isometric mode.

We first obtained an MVIC for IR at the 2 angles previously calculated for the JPS measure at 90% of the IR ROM and 90% of the ER ROM. Three MVIC trials were performed at each target angle, and the highest peak torque of the 3 trials was used to calculate the target force for FR testing. We used a target force equivalent to 50% of the MVIC for both target angles. Previous authors suggested that using 50% of the MVIC for the target force generated less error with the reproduction.[20] To begin the FR measurement, the subject attempted to rotate the dynamometer arm internally while receiving visual feedback regarding the force being produced. Once the subject achieved the target force, he or she was instructed to maintain it for 3 seconds and to concentrate on how much force was being exerted. After 3 seconds, the subject was instructed to relax. We then removed the visual feedback and instructed the subject to reproduce the force. When the subject verbally indicated that he or she had achieved the target force, T1 recorded it for 3 seconds. The measurement was repeated 2 more times for a total of 3 trials at both angles. We calculated the error score for each trial as the absolute difference between the target force and the observed force and used the average of the 3 trials in the analysis.

Statistical Analyses

The Statistical Package for the Social Sciences (version 10.0; SPSS Inc, Chicago, IL) was used to perform all statistical analyses. An a priori level of significance was set at $P <$ .05 for all comparisons.

Reliability

We determined both intertester and intratester instrument reliability using the intraclass correlation coefficient (ICC) formula 2,1. A repeated-measures analysis of variance was used to compare the angles observed by T1 across the 3 trials. The reliability of the JPS and FR error-score measurements and the

Table 1. Intraclass Correlation Coefficient Values for Joint Position Sense and Force-Reproduction Testing Across Days 1 and 2

Target Angles	Joint Position Sense	Force Reproduction
90% Internal rotation range of motion	.981	.981
90% External rotation range of motion	.984	.978

Table 2. Range-of-Motion Measurements (°) and Intraclass Correlation Coefficients for Internal Rotation and External Rotation on Days 1 and 2

Day	Internal Rotation	External Rotation
1	141.2 ± 18.6	30.7 ± 10.4
2	139.1 ± 19.1	32.4 ± 10.4
Intraclass correlation coefficients	0.860	0.906

Table 3. Joint Position Sense and Force-Reproduction Error Scores

Measure and Target Angle	Day 1	Day 2
Joint position sense (°)		
90% Internal rotation range of motion	5.0 ± 3.3	4.2 ± 2.0
90% External rotation and range of motion	4.2 ± 3.3	4.0 ± 2.4
Force reproduction (Nm)		
90% Internal rotation range of motion	10.5 ± 8.2	8.3 ± 6.7
90% External rotation range of motion	8.4 ± 5.3	8.5 ± 9.1

Table 4. Joint Position Sense (°) External-Rotation Trials on Days 1 and 2

Day	Trial 1	Trial 2	Trial 3
1	4.6 ± 3.2	3.9 ± 3.4	3.9 ± 2.5
2	4.1 ± 3.2	3.8 ± 2.9	3.9 ± 3.3

Table 5. Joint Position Sense (°) Internal-Rotation Trials on Days 1 and 2

Day	Trial 1	Trial 2	Trial 3
1	6.7 ± 5.9	4.3 ± 3.5	4.1 ± 3.9
2	4.2 ± 3.4	3.9 ± 2.7	4.4 ± 3.7

Table 6. Force-Reproduction (Nm) External-Rotation Trials on days 1 and 2

Day	Trial 1	Trial 2	Trial 3
1	9.3 ± 8.3	8.9 ± 7.6	7.0 ± 5.7
2	9.6 ± 11.8	7.7 ± 8.3	8.2 ± 8.9

Table 7. Force-Reproduction (Nm) Internal-Rotation Trials on Days 1 and 2

Day	Trial 1	Trial 2	Trial 3
1	13.7 ± 10.7	8.6 ± 7.5	9.2 ± 9.4
2	9.3 ± 10.4	8.9 ± 6.5	6.8 ± 7.1

Table 8. Target-Force Values (Nm) for Force-Reproduction Testing Averaged over Days 1 and 2

Target Angle	Force
90% Internal rotation range of motion	74.92 ± 30.97*
90% External rotation range of motion	63.19 ± 34.30

*Significantly different from external-rotation force value.

ROM measurements were determined using the ICC formula 2,3.

We calculated two 3-way analyses of variance with repeated measures to determine if differences existed among JPS and FR between the 2 days and both target angles and among the 3 trials. Another analysis of variance was used to compare the 2 target forces generated at each angle on both days.

RESULTS

The 10 angles we randomly selected to determine reliability ranged from 15° to 155°. The inclinometer provided a reliable measure, as high intratester (.999) and intertester (.999) reliabilities were observed. These calculations incorporated the recorded angles of T1 and T2 and the 3 measurements of all 10 angles recorded by T1.

Both the JPS and FR measurements were highly reliable, and the ICCs were high between the ROM measurements between days 1 and 2 (Tables 1 through 3). Measuring JPS and FR on consecutive days is a reliable way of measuring proprioception.

No differences were found between the trials of JPS or FR error scores on the 2 days (Tables 4–7). Target forces were significantly higher for IR than for ER target positions (Table 8). Subjects generated significantly more force in the IR position than in the ER position.

DISCUSSION

The relationship between proprioception and dynamic stability continues to be a popular research focus. As the interest in this area has progressed, numerous methods for assessing proprioception have been developed, with each having its own advantages and limitations. Methods for measuring proprioception include custom-made jigs,[11,25,34] electromagnetic tracking,[7,34] and isokinetic dynamometers.[2,6,12,22] The method chosen would depend on which aspect of proprioception interests the researcher. For example, threshold to detection of passive motion measured at slow speeds targets slow-adapting mechanoreceptors such as Ruffini endings and Golgi tendon organs.[3] We used an inclinometer in this study, attached via a hook-and-loop strap and similar in size to a watchband. We think this might offer an advantage over other devices, as it limits the amount of tactile feedback to the subject. Tactile feedback has been suggested to affect proprioception in the knee and ankle.[24,25,42,43] Regardless of the method used, it is extremely important that both the instrument used in the measurement and the measurement techniques are reliable. Otherwise, the validity of the results can be questioned. The inclinometer provides an affordable, reliable, and easy-to-use measure of both ROM and JPS.

Instrument Reliability

We used the Kin Com isokinetic dynamometer to establish the reliability of our inclinometer. We believe this is truly a measure of instrument reliability as the only possible change occurred in the angular positioning of the dynamometer arm. Thus, the mechanical stops and stationary dynamometer arm allowed us to accurately assess the reliability of our instrument. Our results suggest that the inclinometer is a reliable instrument because both intratester and intertester ICCs were high. Furthermore, no significant differences were found when comparing the angles observed between testers or the angles observed among the 3 trials. Also, the ICCs for the ROM measurements between days were high.

Joint Position Sense

The JPS measurement of the shoulder using the inclinometer was reliable, as the ICC was high. Our JPS error scores ranged from 4.0° to 5.0°, scores similar to those measured previously in the shoulder.[2,10,12,14,35] Two conclusions can be drawn from these observations. First, the methods used in the JPS measurement and the investigator were both reliable. Second, the subjects were reliable in their ability to sense joint position on consecutive days. However, all measurements were taken on healthy subjects, and JPS reliability may be affected in an injured population.

We also measured the differences among the trials of all the JPS and FR testing. No differences were noted among the 3 trials of JPS error scores on either day. The subjects were instructed to reposition the target angle 3 times, and no differences were seen among trials and days.

Previous researchers[2,29] suggested that afferent information regarding JPS originates from peripheral mechanoreceptors located in the skin, muscle, and surrounding joint structures. These receptors can include muscle spindles and Golgi tendon organs, which measure changes in the length and tension of the muscle, respectively.[31,32] Control of JPS is most likely a combination of afferent information, efferent response, and some central command.[26] We found no differences between IR and ER JPS error scores. Both target angles were near the end ROM (90%), and the capsule and musculature would be stressed differently at the 2 positions. In the IR position, the external rotators of the shoulder are lengthened compared with the ER position, in which the internal rotators of the shoulder are lengthened. It has been suggested[39] that the capsule in the direction of the translation is the primary restraint and the structures on the opposite side of the joint are the secondary restraints. However, the lengthening of the external rotators versus the internal rotators in the 2 target positions did not affect JPS. We were not able to conclude which receptor provides more information to JPS. Identifying the contribution of specific receptors to proprioception of the shoulder would be helpful in future studies.

It is important to note the lesion site when measuring proprioception or rehabilitating the shoulder. Clinicians need to be aware of which structure may be compromised during rehabilitation movements. The same is true for proprioception measurement. Joint position sense and FR measures are helpful in quantifying proprioception, but clinicians need to avoid movements that stress the injured structure early in the rehabilitation phase while measuring proprioception. We are unaware of any studies to date measuring the effect of pain on shoulder proprioception.

Fatigue and Joint Position Sense

It has been suggested that muscle fatigue can influence receptor information, but its effect on JPS remains unclear.[9] In subjects following a fatigue protocol for the hamstrings and quadriceps muscles, no significant difference between JPS before and after fatigue was measured.[9] Another group measured JPS in the elbow after a biceps fatigue protocol and found the exercised forearm had a consistently larger repositioned angle of almost 5°.[14] The biceps protocol consisted of 2 sets of 50 repetitions separated by 5 minutes. The authors suggested a decrease in information relayed from the receptors due to muscle damage, which led to the overshoot in repositioning. The groups' explanations of their results differed as they speculated about the increase or decrease in afferent information after exercise. Why smaller repositioned angles were produced in one study and larger angles in the other study remains unclear. More studies on JPS could help to identify the specific role of mechanoreceptors in JPS.

Lephart et al[3] have previously illustrated a paradigm in overhand athletes that suggests a relationship between injury and proprioception loss. Several factors can contribute to an injury in the upper extremity, so the direct mechanism is unclear. Fatigue can decrease shoulder proprioception, but its effect on injury in the upper extremity is ambiguous at best.[2]

Force Reproduction

Our study suggests that, along with JPS, FR is also a highly reliable measure of proprioception. Like the JPS measures, the FR ICCs were high. At this time, there are no reports of FR being measured in the shoulder. Our error scores ranged from 8.3 to 10.5 Nm. However, our theory of less error derived from using a 50% MVIC target angle is supported by one group that assessed FR at the elbow.[20] The researchers asked subjects to estimate a force with one limb while generating different forces using the contralateral limb. The subjects had the least amount of error while matching the force at 50% of the MVIC. However, in another study, less error was noted when subjects attempted to reproduce greater relative forces.[19] As in the former study, we also used 50% of the MVIC for FR. However, we calculated error scores while subjects attempted to reproduce force using the ipsilateral limb. No differences were observed between days 1 and 2 of testing on the error scores. It is possible that a decrease in error is associated with a target force equivalent to 50% of the MVIC, which may have contributed to our findings.

Force-Reproduction Trials

We also measured the differences among the trials on all FR testing. There were no significant differences among all trials on both days. The testing session was quite long; subjects completed all the JPS measurements first, followed by the FR testing, and we were concerned about shoulder fatigue affecting the results. If the subjects became fatigued during the testing process, the third trial error scores may have increased compared with the first trials. However, no increases in error scores were observed throughout the testing, which suggests the subjects were not fatigued. We were also concerned about a learning effect. Because the subjects were shown the target angle before reproduction on all 3 trials, we wondered if the error scores would decrease over the trials, indicating not an increase in proprioception but an increase in accuracy due to the excessive time spent at the target angle. However, there were no differences among the trials, so this was not the case.

Although greater force was generated in the IR position, no significant differences in FR were observed between the 2 angles on either day. This can be explained using a length-force curve. The ER position, being 90% of the total ROM, has the internal rotator muscles lengthened more than in the IR position and, therefore, the muscles cannot generate as much force as in the IR position. Despite the changes in length and force generated, no significant difference was seen between FR IR and ER error scores. Thus, tissue length and stretch did not affect FR.

Force-Reproduction Control

It has been suggested that proprioception at proximal joints may be more efficient than at distal joints.[27] Distal muscles possess dense corticospinal projections as compared with proximal muscles.[19] Subthreshold motor commands can be directed to single motor units of extremely low threshold in the intrinsic hand muscles but not to muscles of the forearm.[27] The researchers hypothesized that a resulting decrease in FR might occur, but their results did not support that prediction. However, their theory may hold true for more proximal muscles encompassed in the shoulder. This is a concern, as stability of the shoulder requires specific motor control and timing of the dynamic restraints. To our knowledge, we are the first to measure FR in the ipsilateral shoulder using various positions of rotation. A measure of FR might be a better indicator of proprioception because of an increase in afferent information as compared with JPS.

In one of the original FR studies, the authors used contralateral, limb-matching isometric forces while vibrating agonist and antagonist muscles.[28] The vibration of agonist muscles excited the spindle primary endings, resulting in a stronger contraction requiring less ‘‘effort.’’ As a consequence, the contralateral limb produced less force than the reference limb. Conversely, during antagonist muscle excitation, a disynaptic reciprocal inhibition of the motor neurons of the contracting muscle caused a loss of force and a resulting increase in effort required to achieve the target force.[28] The matching limb generated more force than the target force as a result. Although the tension in the agonist muscle does not change because the weight does not change, the opposite limb generates a different force. An increase in this efferent input may correspond with an increase in the perceived magnitude of the force of contraction, even when the force produced by the muscle remains constant.[29,37] The fact that the error in weight matching can be decreased by instructing the subjects to ‘‘keep the force the same’’ may suggest that the descending signals or corollary discharges can provide more information to FR than mechanoreceptors.[28,29] However, in the same study, the authors also assessed the contribution from the Golgi tendon organs.[28] The subjects maintained a constant force with their arms while the agonist muscles were vibrated. The subjects were able to maintain the force with 20% accuracy. When the subjects matched the force with relative accuracy during the vibration stimulus, the authors suggested that the subjects used their sense of tension to maintain the force produced. The conclusion was that both mechanisms are important to the control of FR. It has also been proposed that the receptor information could be involved in scaling the corollaries of the descending motor command.[36]

The use of vibration to affect proprioception is not common during rehabilitation, but it may have an indirect clinical benefit. The method of using an intervention, measuring an outcome, and inferring control can lead to more understanding of control of proprioception. Further understanding of the mechanism of proprioception would allow clinicians to use that knowledge to make better rehabilitation tools.

The conflicting results make it difficult to fit an equation to the response of fatigue and FR, complicating the theory behind the mechanism for FR. Previous investigators measured different handgrip forces and their respective sense of effort or ‘‘apparent force experienced’’ over time.[18] A regression involving a power function described the relationship between perceived force and force exerted. Other researchers, using contralateral limb matching in the elbow, found a linear increase in the perceived force during constant force contractions during fatigue.[15] Further research on fatigue and FR could establish the relationship between the two.

Limitations

Some limitations of our study include the inability to randomize the order of JPS and FR testing. Because fatigue affects both JPS and FR, we decided to measure JPS first on both days, followed by the FR, as the testing for JPS is less strenuous than the testing for FR. No differences were noted among all the trials for JPS and FR testing. If fatigue had been present, we would have seen an increase in error scores from trial 1 to trial 3. We believed conducting the JPS testing before any muscle contractions provided the ideal method.

CONCLUSIONS

Joint position sense and force reproduction are reliable measures when testing proprioception. Clinicians might be interested in FR because it may be a better measure of shoulder proprioception. Force reproduction may provide more muscle activity and afferent information than JPS during proprioception measurement. More studies measuring proprioception in an injured population or during rehabilitation are needed to demonstrate the significance of FR. Clinical measurements of JPS and FR can be used to track progression during the rehabilitation process, noting improvements, and providing some motivation to the athlete to improve proprioception between visits. Future studies on the mechanism of JPS and FR would be informative in helping us to understand the afferent and efferent information being processed and allowing clinicians to improve their proprioception rehabilitation.

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